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Title: Fusion Prototypic Neutron Source for near-term fusion material testing

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Oak Ridge National Laboratory

Fusion Prototypic Neutron Source for near-term fusion material testing

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Goals for the Fusion Prototypic Neutron Source (FPNS) are clear

Address the long-standing challenge to fusion energy by enabling the development of high-performance materials resistant to DT fusion neutrons

- Build a ***near-term, cost-efficient*** neutron source to advance scientific understanding of materials under simulated D-T neutron irradiation
- Validate and verify a nuclear design methodology for next-step fusion devices and beyond

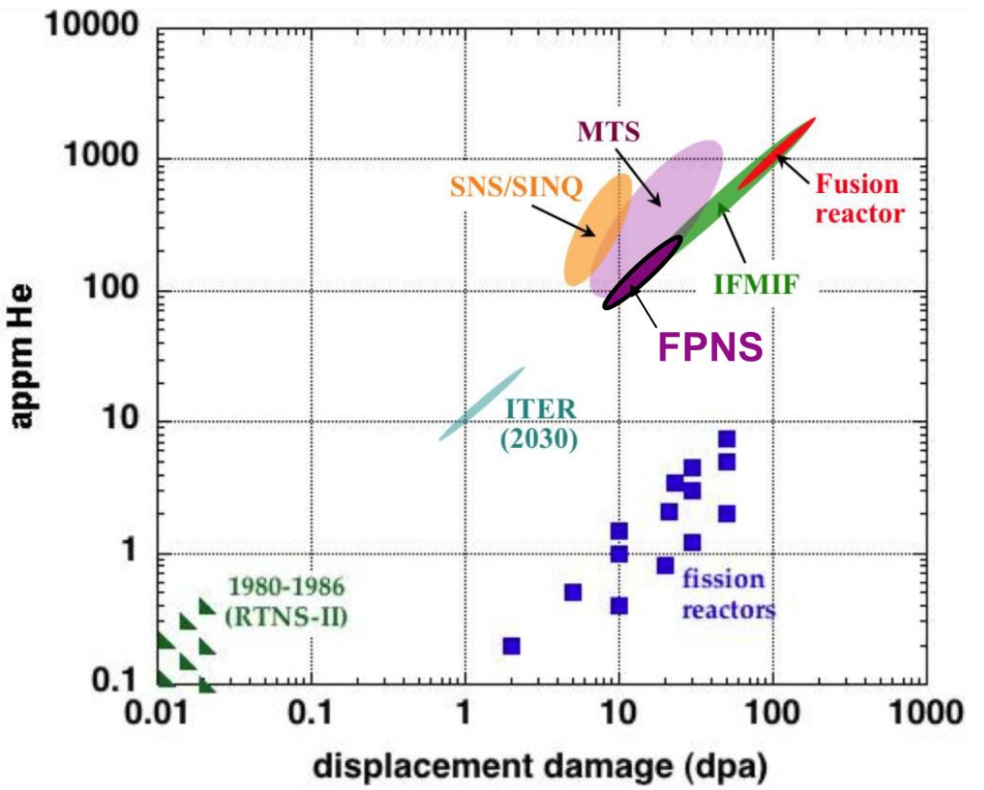
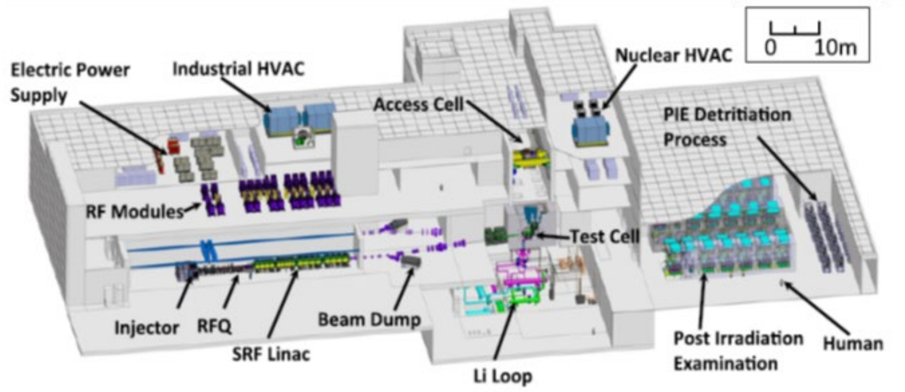


Figure adapted from FESAC Report DOE/SC-0149, February 2012

There is a long history of proposed fusion neutron facilities

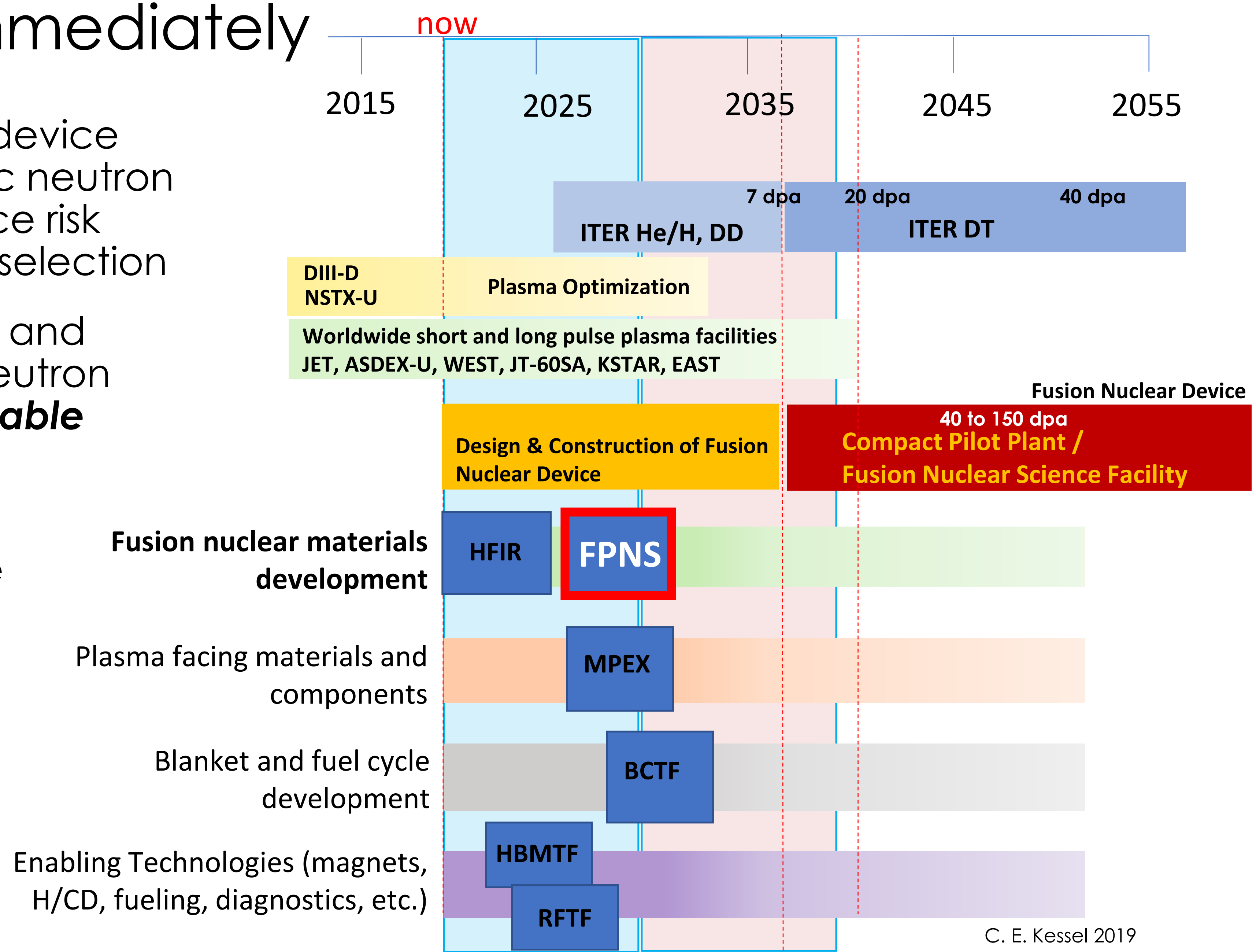
- *Gaps and Priority (2005, 2007)*, *ReNeW (2009)* and multiple other community reports have promoted material testing in a Fusion Prototypic Neutron Source style facility
- The identified need for a fusion neutron facility dates to at least the ***1970's***
- Many facilities proposed: FMIT ('75-'84), IFMIF ('94-present), MTS
- Only the RTNS-I & II were built and operated at <0.1 dpa between 1979 and 1987
- International Fusion Materials Irradiation Facility (IFMIF) is being designed and technology prototyped by the EU/Japan
- Build cost of IFMIF estimated at >$1.25B



Artistic view of IFMIF main building; adapted from J. Knaster et. All. (2017) "Overview of the IFMIF/EVEDA project" *Nucl. Fusion* 57, 102016

Future device timelines require a material irradiation facility to start immediately

- Next step fusion nuclear device design requires prototypic neutron irradiation results to reduce risk associated with material selection
- Assume 5 years to design and build Fusion Prototypic Neutron Source (FPNS) ***using available technology***
- Relevant neutron damage results available in ***early 2030's***



C. E. Kessel 2019

The 2018 community workshop defined near-term neutron facility parameters to advance material science

- Focus on scientific understanding of materials ***in prototype neutron spectrum and temperature***
- ***Will not provide an engineering materials database***
- Near-term = Existing technology with low R&D requirement
- Limited sample volume

Parameter	Guideline
Damage rate	~8–11 dpa/calendar year (Fe)
Spectrum	~10 appm He/dpa (Fe)
Sample volume in high flux zone	≥50 cm^3
Temperature range	~300–1000 °C
Temperature control	Three independently monitored and controlled regions
Flux gradient	≤20%/cm in the plane of the sample

FY2019 funding has been received to explore feasibility of three near-term FPNS technologies

1. D-Li stripping reaction driven by a 30 to 40 MeV, ~100 mA D^+ accelerator into a liquid Li target
   – reduced-scale facility compared to the International Fusion Materials Irradiation Facility (IFMIF)
   – build on the extensive technology development by international community
2. A matrix of high-intensity D-T gas target neutron sources
   – Based on commercialized and deployed technology by Phoenix LLC
3. Spallation neutron source tailored for fusion neutron spectrum
   – Target station added to the existing Los Alamos Neutron Science Center (LANSCE) accelerator

US based D-Li neutron irradiation facility

- 30 to 40 MeV D^+ ions into a flowing liquid Li target result in a forward biased cone of neutrons with an energy spectrum peaked at ~40% of the deuteron energy – first proposed for fusion testing in 1976 [1]

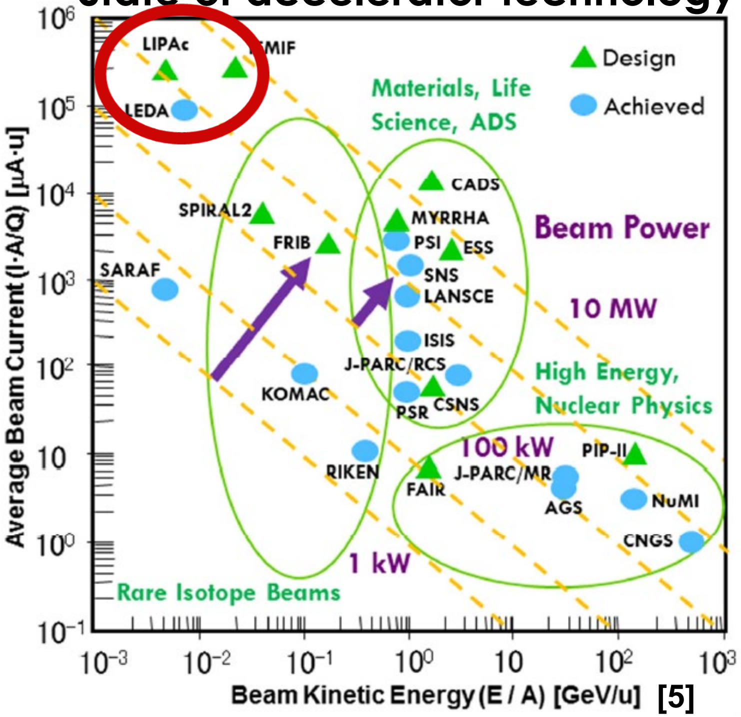
- A reduced power IFMIF design could meet the 10 dpa/year 50 cm^3 requirements of the US fusion materials program. [2]

- Several relevant accelerator and target technologies have been demonstrated or are in the process of being prototyped
  - LEDA experiments at demonstrated CW operation of an RFQ with 100 mA H^+ beam [3]
  - EVEDA LIPAc project scheduled to test ion source, RFQ, and first cryomodule [4]
  - EVEDA ELTL demonstrated Li target [4]

- R&D still required for a 3 to 5 MW, full-CW, D^+ accelerator and integration with Li target

- Can an accelerator and Li target be built and coupled with existing materials examination facilities to create a feasibile facility?

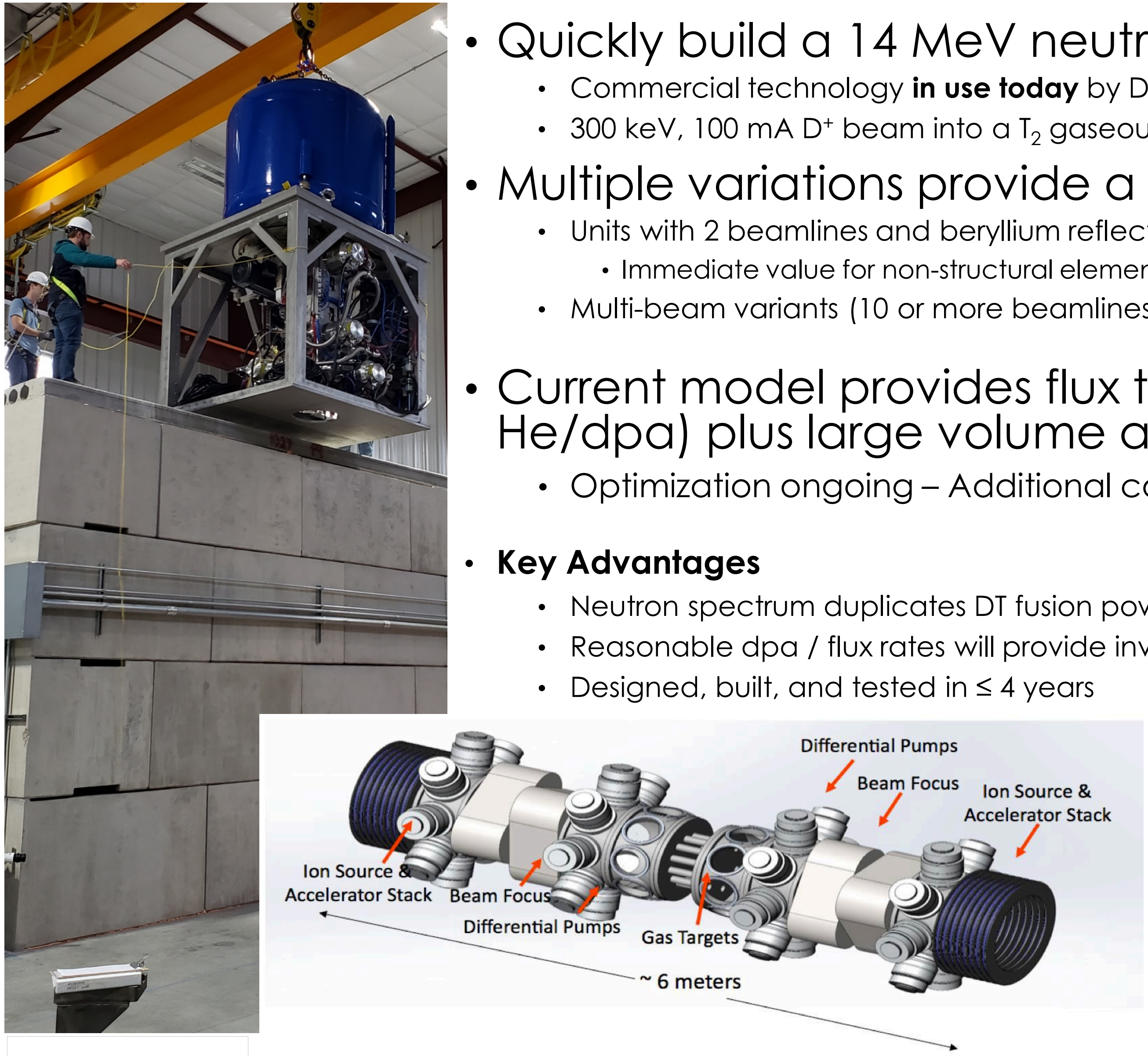
State of accelerator technology



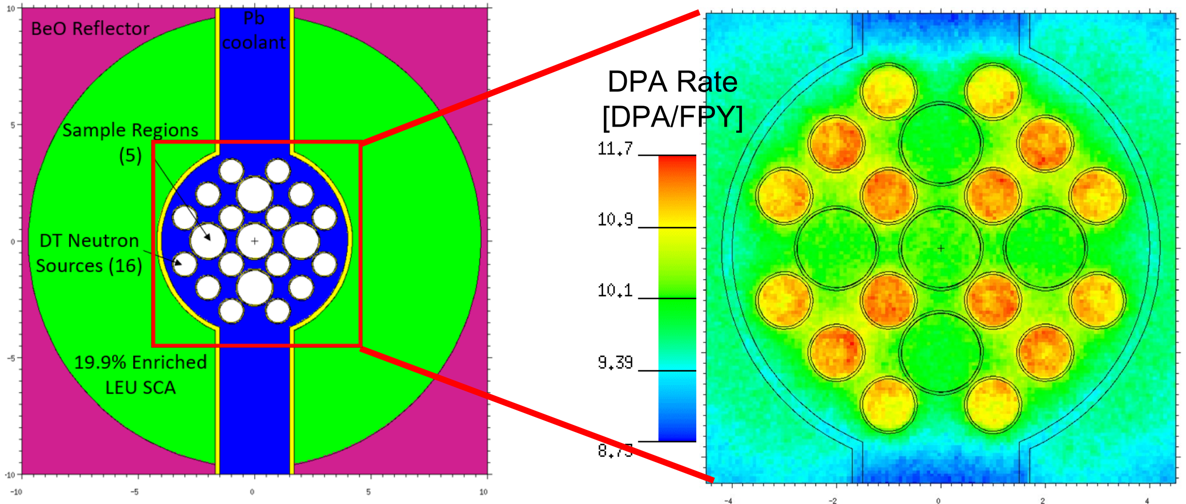
[5]

1. P. Grand et al. (1976) “An Intense Li(d,n) Neutron Radiation Test Facility for Controlled Thermonuclear Reactor Materials Testing,” *Nuclear Technology* 29:3, 3207–336, DOI: 10.13182/NT76-A31598.J.
2. R. Heidinger et al. (2014) “Technical analysis of an early fusion neutron source based on the enhancement of the IFMIF/EVEDA accelerator prototype,” *Fusion Engineering and Design* 89, 2136–2140.
3. L. Young et al. (2000) “High power operations of LEDA,” LINAC 2000 (Monterey, USA).
4. Knaster et al. (2017) “Overview of the IFMIF/EVEDA project” *Nucl. Fusion* 57, 102016.
5. J. Wei. (2014) “The Very High Intensity Future,” IPAC2014, DOI: 10.18429/IPAC2014-MOYBA01

Leveraged Commercial Pathway

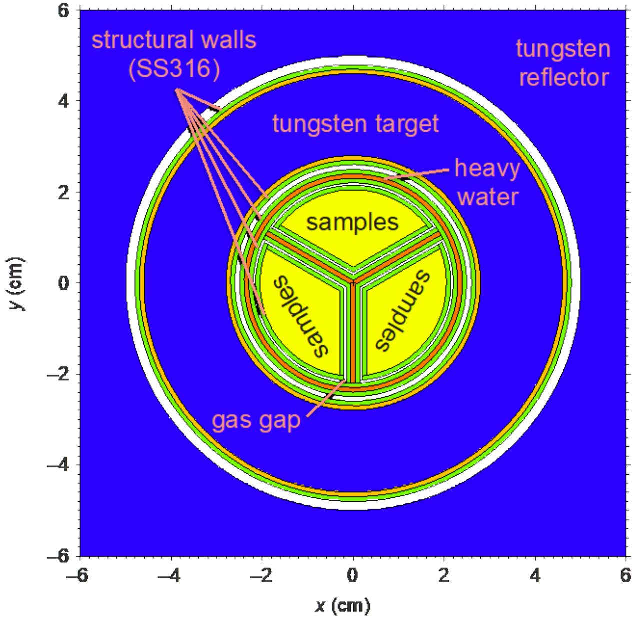


- Quickly build a 14 MeV neutron irradiation facility
  - Commercial technology **in use today** by DoD, commercial, and international customers
  - 300 keV, 100 mA D^+ beam into a T_2 gaseous target **~10^{14} n/s (14 MeV) per beamline**
- Multiple variations provide a range of dpa rates and energy spectra
  - Units with 2 beamlines and beryllium reflectors can be operating in **12 months**
    - Immediate value for non-structural elements (breeder blankets, superconducting magnets, diagnostics, etc)
  - Multi-beam variants (10 or more beamlines) can be online ***in <4 years***
- Current model provides flux trap with 10 dpa/fpy over 50 cm^3 (2 appm He/dpa) plus large volume at lower dose
  - Optimization ongoing – Additional configuration at 5 dpa/fpy and 10 appm He/dpa
- **Key Advantages**
  - Neutron spectrum duplicates DT fusion power plant, ensuring the proper ratio of transmutation products (e.g. helium)
  - Reasonable dpa / flux rates will provide invaluable data to bridge between current state and IFMIF
  - Designed, built, and tested in ≤ 4 years

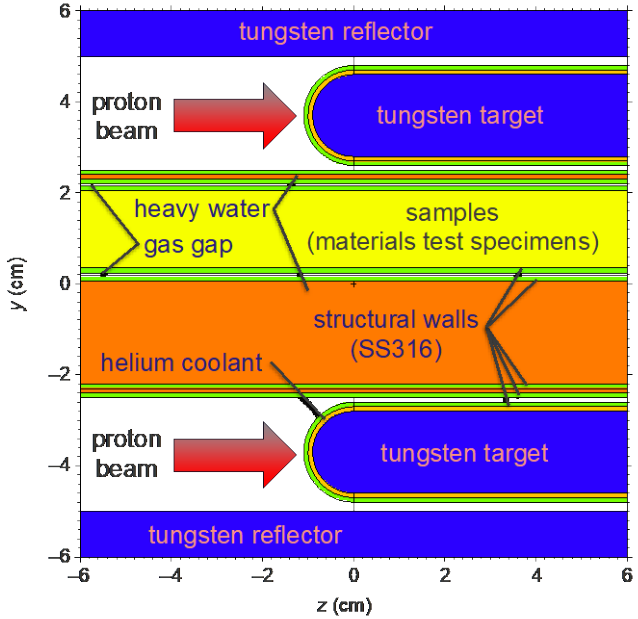


Spallation target tailored for a fusion prototypic neutron source at LANSCE (LANL)

- 1-MW proton beam rastered on an annular tungsten target generating 10^{17} neutrons/s
- Test specimens occupy flux trap that is divided into 3 temperature-controlled 120° sectors
- In the 53 cm^3 peak-flux test volume:
  - Peak damage rate is 20.6 dpa/fpy or 8 dpa/CY for 3400 hours/CY of full-power beam on target
  - He-to-dpa ratio is 14.6 appm He/dpa
- Low technical risk using existing technology
- Can be built in existing experimental hall with two available hot cells



Vertical cut perpendicular to proton beam direction showing annular W target and structural details of the central cylinder housing the test specimens.



Vertical cut parallel to proton beam direction showing annular target and test specimens occupying central hole.

Fusion Prototypic Neutron Source - Summary

Address the long-standing challenge to fusion energy by enabling the development of high-performance materials resistant to DT fusion neutrons

- Timeline for fusion nuclear devices require a near-term prototypic neutron irradiation facility
- Advancement of scientific understanding of neutron irradiated materials needs ~10 dpa/yr at 10 appm He/dpa in a 300 to 1000 °C environment
- FES is currently exploring three potential technologies and evaluating based on performance, cost and schedule